The cLFV searches and studies with the BESIII experiment

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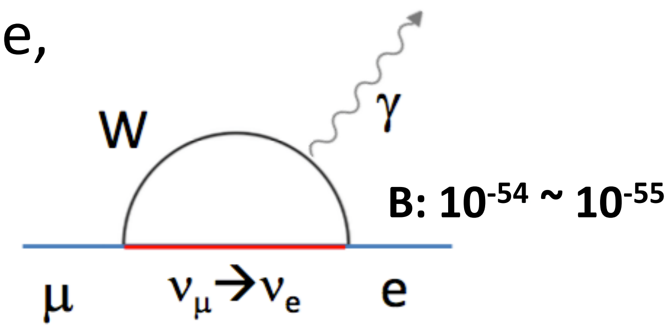
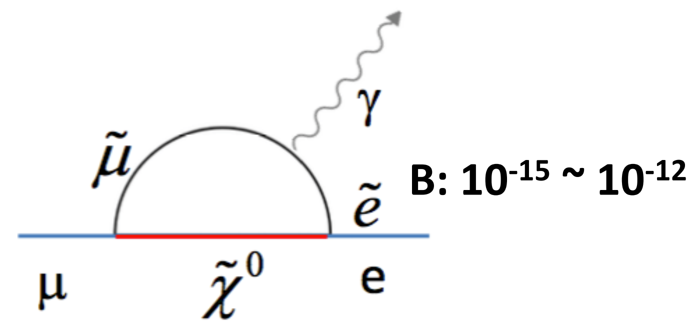
Why charged Lepton Flavor Violation?

- The non-zero neutrino masses and mixing can introduce flavor transitions, but the expected branching fractions are at an extremely rare level. For example, with the present knowledge on neutrino mixing parameters, the branching fraction of the cLFV process $\mu \rightarrow e\gamma$ is only about 10^{-55}.
- Thus, searching for the cLFV events which are SM forbidden would be clear signal of physics beyond the SM.
- For example,





- SM prediction
- SM + ν oscillation

- Beyond SM (e.g. SUSY)

Why charged Lepton Flavor Violation?

- Theoretical prospects for μ→e, μN→eN and μ→3e

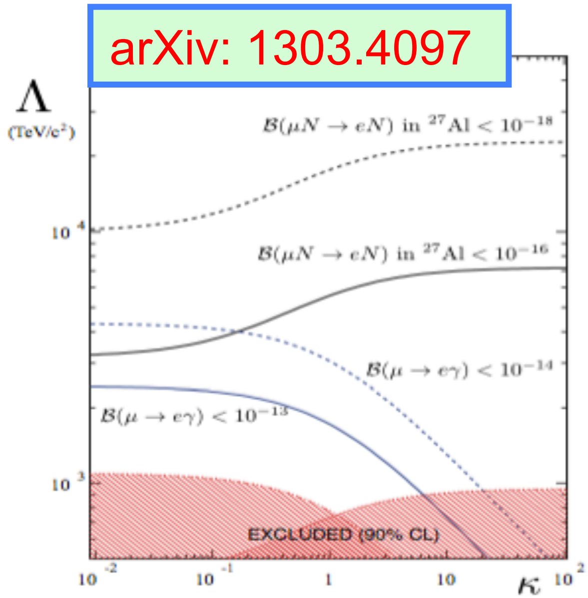


Figure 1: Sensitivity of a $\mu \to e$ conversion in ^{27}Al that can probe a normalized capture rate of 10^{-16} and 10^{-18}, and of a $\mu \to e\gamma$ search that is sensitive to a branching ratio of 10^{-13} and 10^{-14}, to the new physics scale Λ as a function of κ, as defined in Eqn. (2). These correspond roughly to the discovery limits for the Mu2e experiment at the FNAL Booster, currently approved, and an "ultimate experiment." The $\mu \to e\gamma$ values are indicative of the signals-event sensitivity for MEG and its approved upgrade. Also depicted are the currently excluded regions of this parameter space from the MEG and SINDRUM-II experiments. See Sec 3 for references and explanations. Figure and caption adapted from de Gouvêa and Vogel [2013].

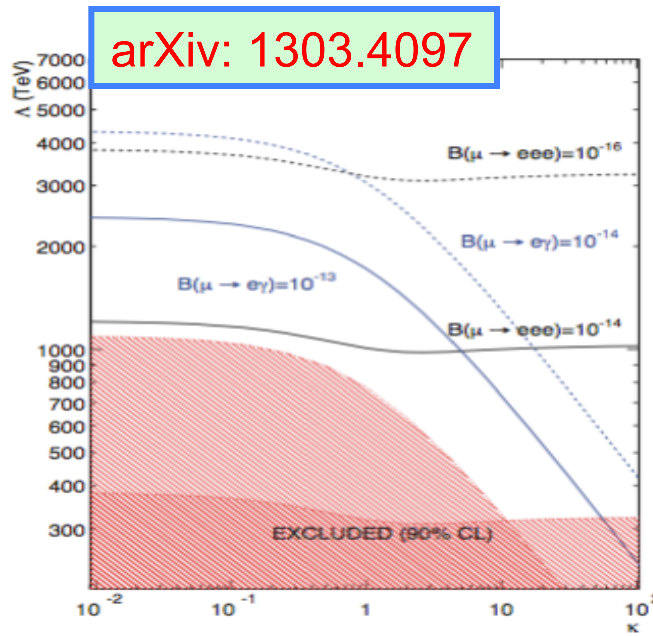
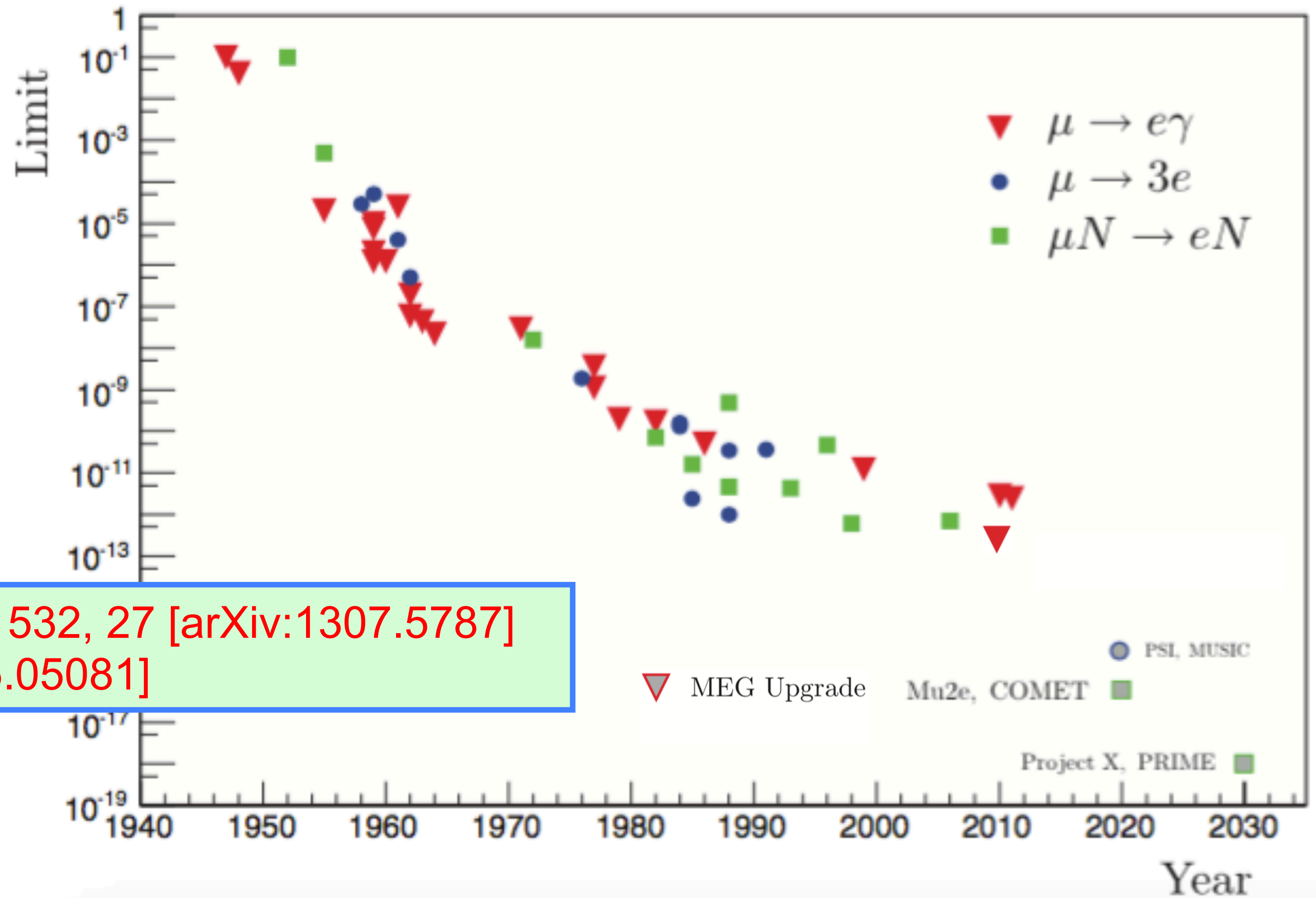


Figure 2: Sensitivity of a $\mu \to eee$ experiment that is sensitive to branching ratios 10^{-14} and 10^{-16}, and of a $\mu \to e\gamma$ search that is sensitive to a branching ratio of 10^{-13} and 10^{-14}, to the new physics scale Λ as a function of κ Eqn. (3). These correspond roughly to the discovery limits for the Mu2e experiment at the FNAL Booster, currently approved, and an "ultimate experiment". The $\mu \to e\gamma$ values are indicative of the signals-event sensitivity for MEG and its approved upgrade. Also depicted are the currently excluded regions of this parameter space from the MEG and SINDRUM-II experiments. See Sec 3 for references and explanations. Figure and caption adapted from de Gouvêa and Vogel [2013].

Why charged Lepton Flavor Violation?

- And experimental results for μ→e, μN→eN and μ→3e



Phys. Rept. 532, 27 [arXiv:1307.5787]
[arXiv: 1605.05081]

Experimental status

- LFV in Meson decays

Channel	Upper limit	Experiment
$\pi^0 \to \mu^\pm e^\mp$	3.59×10^{-10}	KTeV
$\eta \to \mu^\pm e^\mp$	6×10^{-6}	Saturne SPES2
$K_L^0 \to \pi^0 \mu^\pm e^\mp$	7.56×10^{-11}	KTeV
$K_L^0 \to 2\pi^0 \mu^\pm e^\mp$	1.64×10^{-10}	KTeV
$K_L^0 \to \mu^+ e^-$	4.7×10^{-12}	BNL E871
$K^+ \to \pi^+ \mu^+ e^-$	1.3×10^{-11}	BNL E865, E777
$D^+ \to \pi^+ \mu^\pm e^\mp$	3.4×10^{-5}	Fermilab E791
$D^+ \to K^+ \mu^\pm e^\mp$	6.8×10^{-5}	Fermilab E791
$D^0 \to \mu^\pm e^\mp$	8.1×10^{-7}	BaBar
$D_s^+ \to \pi^+ \mu^\pm e^\mp$	6.1×10^{-4}	Fermilab E791
$D_s^+ \to K^+ \mu^\pm e^\mp$	6.3×10^{-4}	Fermilab E791
$B^0 \to \mu^\pm e^\mp$	9.2×10^{-8}	BaBar (347 fb^{-1})
$B^0 \to \tau^\pm e^\mp$	1.1×10^{-4}	CLEO (9.2 fb^{-1})
$B^0 \to \tau^\pm \mu^\mp$	3.8×10^{-5}	CLEO (9.2 fb^{-1})
$B^+ \to K^+ e^\pm \mu^\mp$	9.1×10^{-8}	BaBar (208 fb^{-1})
$B^+ \to K^+ e^\pm \tau^\mp$	7.7×10^{-5}	BaBar (348 fb^{-1})
$B_s^0 \to e^\pm \mu^\mp$	6.1×10^{-6}	CDF (102 pb^{-1})

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Experimental status

- LFV in quarkonium resonances decay

$\ell_1\ell_2$	$\mu\tau$	$e\tau$	$e\mu$
$\mathcal{B}(\Upsilon(1S)\to\ell_1\ell_2)$	6.0×10^{-6}	–	–
$\mathcal{B}(\Upsilon(2S)\to\ell_1\ell_2)$	3.3×10^{-6}	3.2×10^{-6}	–
$\mathcal{B}(\Upsilon(3S)\to\ell_1\ell_2)$	3.1×10^{-6}	4.2×10^{-6}	–
$\mathcal{B}(J/\psi\to\ell_1\ell_2)$	2.0×10^{-6}	8.3×10^{-6}	1.6×10^{-7}
$\mathcal{B}(\phi\to\ell_1\ell_2)$	n/a	n/a	4.1×10^{-6}

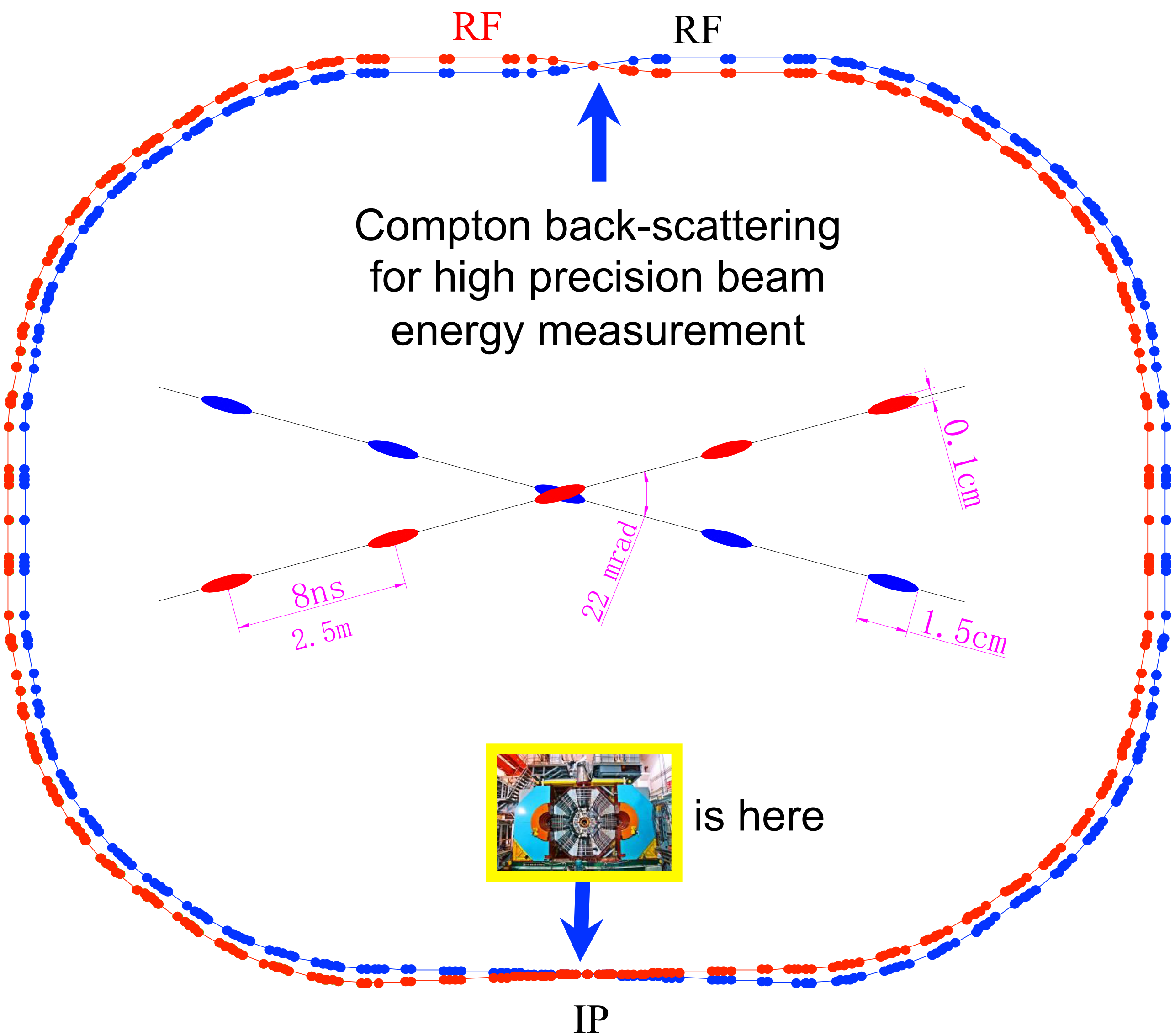
Experimental status

- LFV in quarkonium resonances decay

$\ell_1\ell_2$	$\mu\tau$	$e\tau$	$e\mu$
$\mathcal{B}(\Upsilon(1S)\to\ell_1\ell_2)$	6.0×10^{-6}	–	–
$\mathcal{B}(\Upsilon(2S)\to\ell_1\ell_2)$	3.3×10^{-6}	3.2×10^{-6}	–
$\mathcal{B}(\Upsilon(3S)\to\ell_1\ell_2)$	3.1×10^{-6}	4.2×10^{-6}	–
$\mathcal{B}(J/\psi\to\ell_1\ell_2)$	2.0×10^{-6}	8.3×10^{-6}	1.6×10^{-7}
$\mathcal{B}(\phi\to\ell_1\ell_2)$	n/a	n/a	4.1×10^{-6}

Beijing Electron Positron Collider II (BEPCII)

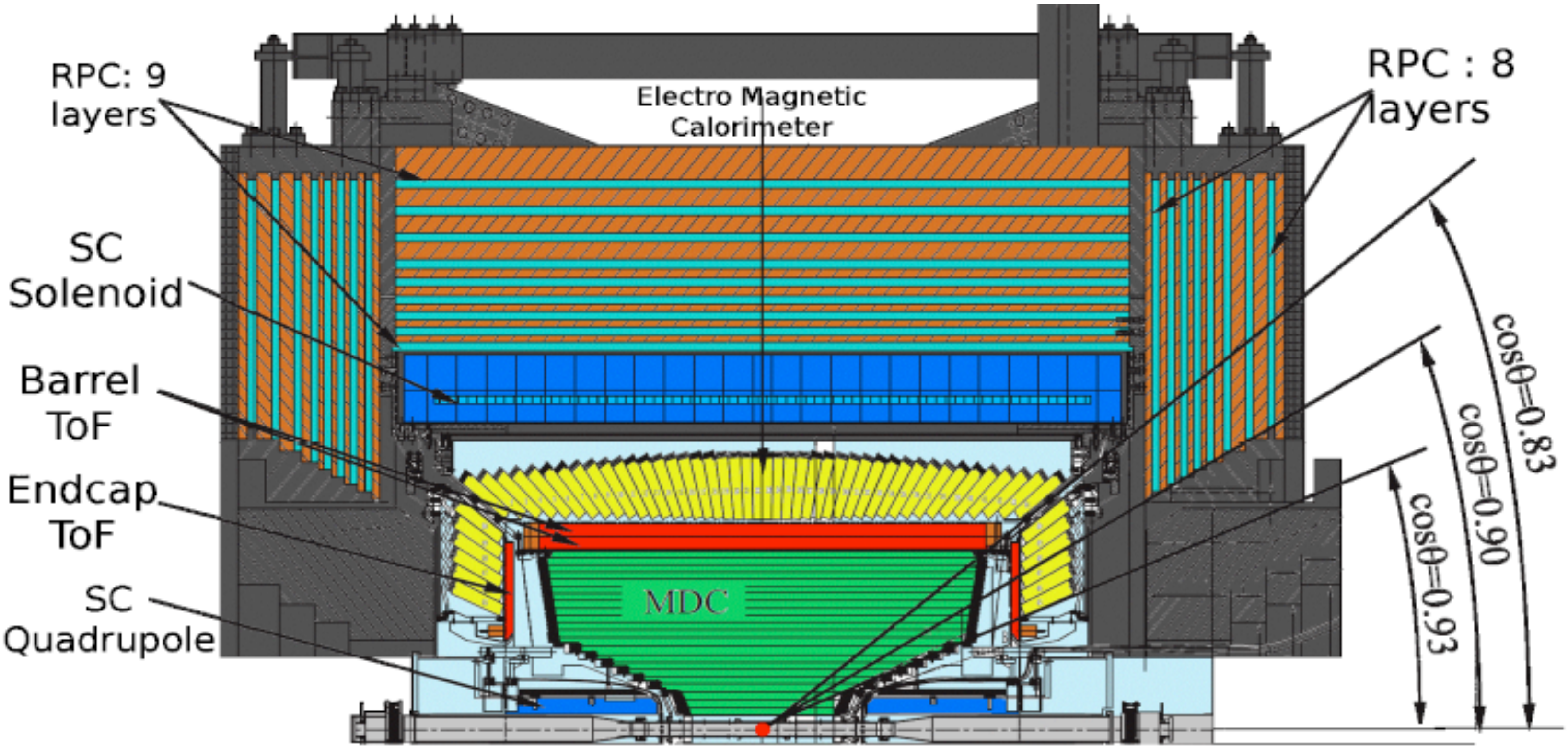
BEPCII: a double-ring machine



Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV


/home21/home/zhaozhuo/setup/liferateNew.edl
2016/04/05 22:29:41
Luminosity 10.00 E32/cm^2/s
e+
e−
Energy [GeV]
1.8833
1.8830
Current [mA]
849.97
852.83
Lifetime [hr]
1.52
2.27
Inj.Rate [mA/min]
0.00
0.00

BESIII Detector



Wire tracker (no Si); TOF + dE/dx for PID; CsI Ecal ; RPC muon

BESIII Collaboration

US (4)

Univ. of Hawaii
Carnegie Mellion Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (14)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Univ. of Ferrara, Frascati Lab
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
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Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

India (1)

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Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
……

~450 members
61 institutions from 13 countries

J/ψ Data Sample

Huge and clean data which provide a good lab to probe rare decays such as LFV process.

$J/\psi \to e\mu$ at BESIII (1)

Phys. Rev. D 87 (2013) 112007

Decay mode	BESII upper limit	BESIII upper limit	Other experiment
$J/\psi \to e\mu$	1.1×10^{-6} (58M)	1.6×10^{-7} (225M)	-
$J/\psi \to e\tau$	8.3×10^{-6} (58M)	-	-
$J/\psi \to \mu\tau$	2.0×10^{-6} (58M)	-	-

- Event topology: two opposite, back-to-back, charged tracks, no obvious extra EMC showers
- Most of the backgrounds are from $J/\psi \to e^+e^-$, $J/\psi \to \mu^+\mu^-$, $J/\psi \to \pi^+\pi^-$, $J/\psi \to K^+K^-$, $e^+e^- \to e^+e^-(\gamma)$ and $e^+e^- \to \mu^+\mu^-(\gamma)$
- To suppress these backgrounds, several powerful criteria are employed.

$J/\psi \to e\mu$ at BESIII (2)

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- To suppress backgrounds from electron mis-ID from $J/\psi \to e^+e^-$, $e^+e^- \to e^+e^-(\gamma)$,

  (1) no associated hits in the MUC;

  (2) 0.95 <E/p< 1.50 GeV, where E is the energy deposit in the EMC and p the momentum measured by the MDC;

  (3) the absolute value of $\chi^e_{dE/dx}$ (the difference between measured and expected dE/dx for electron hypothesis over its resolution) should be less than 1.8;

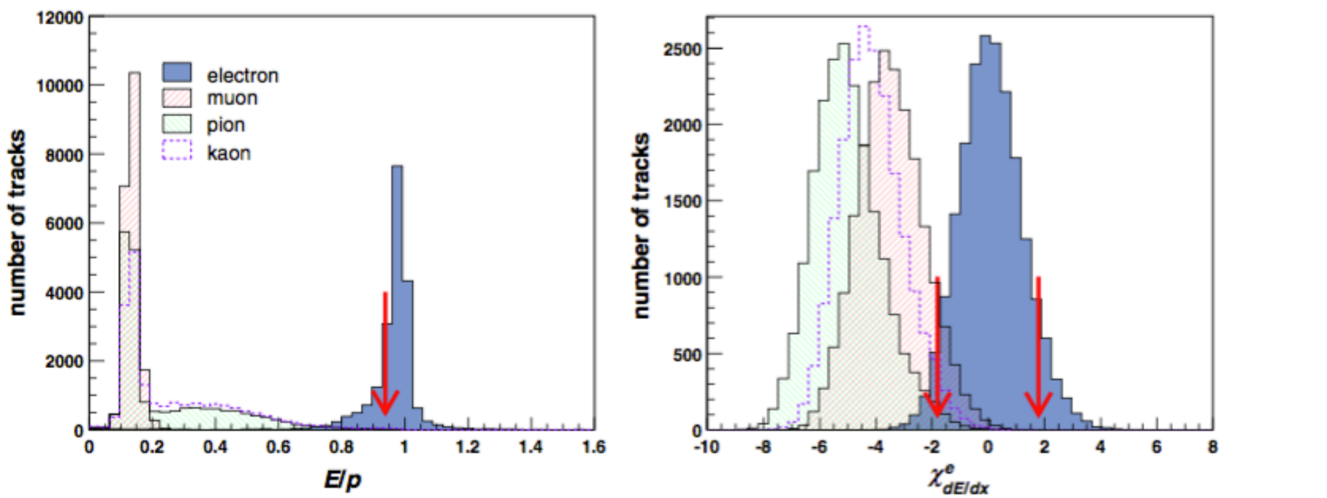

FIG. 1 (color online). The distributions of E/p (left) and $\chi^e_{dE/dx}$ (right) for the simulated electron, muon, pion, and kaon samples.

$J/\psi \to e\mu$ at BESIII (3)

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- To suppress backgrounds from muon mis-ID from $J/\psi \to \mu^+\mu^-$, $e^+e^- \to \mu^+\mu^-(\gamma)$,
  (1) Penetration depth in the MUC larger than 40 cm;
  (2) E/p<0.5 GeV and 0.1 <E< 0.3 GeV
  (3) the absolute value of $\chi^e_{dE/dx}$ (the difference between measured and expected dE/dx for electron hypothesis over its resolution) should be less than -1.8;

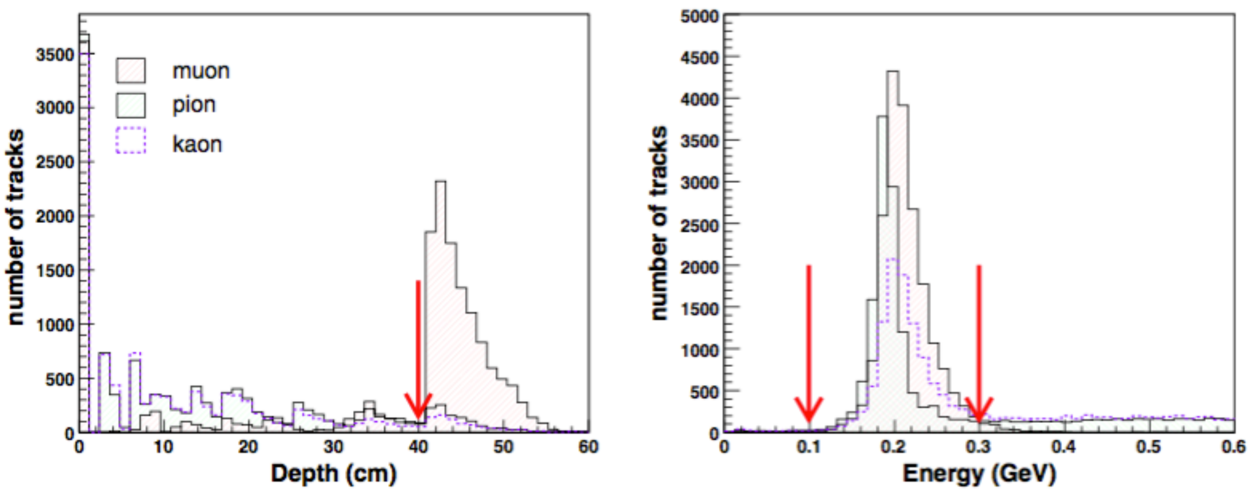

FIG. 2 (color online). The distributions of the penetration depth in the MUC (left) and the deposited energy in the EMC (right) for the simulated muon, pion, and kaon samples.

J/ψ → eμ at BESIII (4)

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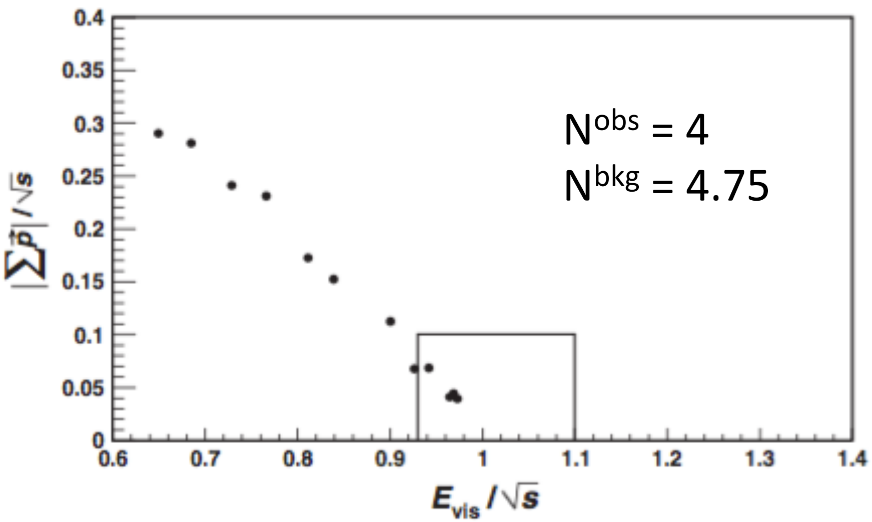

FIG. 3. A scatter plot of $E_{vis}/\sqrt{s}$ versus $|\Sigma\vec{p}|/\sqrt{s}$ for the J/ψ data. The indicated signal region is defined as $0.93 \le E_{vis}/\sqrt{s} \le 1.10$ and $|\Sigma\vec{p}|/\sqrt{s} \le 0.1$.

TABLE I. Summary of systematic uncertainties (%).

Sources	Error
$e^{\pm}$ tracking	1.00
$\mu^{\pm}$ tracking	1.00
$e^{\pm}$ ID	0.62
$\mu^{\pm}$ ID	0.04
Acollinearity, acoplanarity	5.36
Photon veto	1.19
$N_{J/\psi}$	1.24
Total	5.84

With 225 M J/ψ data

$B(J/\psi \to e\mu) < N^{UL}_{obs}/(N_{J/\psi}\varepsilon) < \mathbf{1.6\times10^{-7}}$ @ 90% C.L.

where N^{UL}_{obs} is calculated based on the POLE program which is a Feldman-Cousins method including the number of observed events, the number of background events and its uncertainty, and the systematic uncertainties.

Prospect for $J/\psi \to e\tau$ at BESIII

Simulated based on BESIII software and hardware systems

- $J/\psi \to e\tau$, $\tau \to \mu \upsilon_\mu \upsilon_\tau$
- Event topology: two opposite charged tracks, two missing tracks
- Most of the backgrounds are from $J/\psi \to \pi^+ K_L K^-$, $J/\psi \to K_L K_L$, $J/\psi \to K^{*0} K^0$
- After background suppression, the detection efficiency is estimated to be 14%

With 1300 M J/ψ data

$$B(J/\psi \to e\tau)^{sensitivity} < N^{UL}_{obs}/(N_{J/\psi}\varepsilon) < 6.3\times10^{-8} \text{ @ } 90\% \text{ C.L.}$$

where N^{UL}_{obs} is calculated based on the POLE program which is a Feldman-Cousins method including the number of background events and its uncertainty, and the systematic uncertainties (assumed to be 5%), where the number of observed events is set to be zero.

Prospect for J/ψ → eτ at BESIII

Simulated based on BESIII software and ha… …re systems

- J/ψ → eτ, τ→$\mu\upsilon_{\mu}\upsilon_{\tau}$
- Event topology: two opposite charged tracks … tracks
- Most of the backgrounds are from … $K_L K_L$, J/ψ→$K^{*0}K^{0}$
- After background suppr… efficiency is estimated to be 14%…

With 1300 M J/ψ data

B(J/ψ → … …s/($N_{J/\psi}\varepsilon$)< 6.3×10^{-8} @ 90% C.L.

Result with experimental data is on the way

whe… …sed on the POLE program which is a Feldman-C… …g the number of background events and its unc… …e systematic uncertainties (assumed to be 5%), where the n… observed events is set to be zero.

Prospect for $J/\psi \to \mu\tau$ at BESIII

Simulated based on BESIII software and hardware systems

- $J/\psi \to \mu\tau$, $\tau \to e\upsilon_e\upsilon_\tau$
- Event topology: two opposite charged tracks, two missing tracks
- Most of the backgrounds are from $J/\psi \to \pi^+ K_L K^-$, $J/\psi \to K_L K_L$, $J/\psi \to K^{*0} K^0$
- After background suppression, the detection efficiency is estimated to be 19%

With 1300 M J/ψ data

$$B(J/\psi \to \mu\tau)^{\text{sensitivity}} < N^{UL}_{obs}/(N_{J/\psi}\varepsilon) < 7.3\times10^{-8} \text{ @ 90\% C.L.}$$

where N^{UL}_{obs} is calculated based on the POLE program which is a Feldman-Cousins method including the number of background events and its uncertainty, and the systematic uncertainties (assumed to be 5%), where the number of observed events is set to be zero.

Prospect for $J/\psi \to \mu\tau$ at BESIII

Simulated based on BESIII software and har... ...re systems

- $J/\psi \to \mu\tau$, $\tau \to e\upsilon_e\upsilon_\tau$
- Event topology: two opposite charged tracks ... tracks
- Most of the backgrounds are from ... $K_L K_L$, $J/\psi \to K^{*0}K^0$
- After background suppre... ...efficiency is estimated to be 19...

With 1300 M J/ψ data

$B(J/\psi$ ... $)/(N_{J/\psi}\varepsilon)<$ 7.3×10^{-8} @ 90% C.L.

whe... ...sed on the POLE program which is a Feldman-C... ...g the number of background events and its unc... ...e systematic uncertainties (assumed to be 5%), where the n... observed events is set to be zero.

Result with experimental data is on the way

Summary

- With the world largest e^+e^- annihilation J/ψ data including more than 225 million J/ψ events, the BESIII collaboration got the leading upper limit on **$J/\psi \rightarrow e\mu$** decay.
- Better upper limits on **$J/\psi \rightarrow e\tau$** and **$J/\psi \rightarrow \mu\tau$** based on 1300 million J/ψ events are coming soon.
- New data taking plan has been approved! Better constraints can be expected.


Thank you !